Brazilian Journal of Poultry Science
Revista Brasileira de Ciência Avícola

ISSN 1516-635X 2019 / v.21 / n.2 / 001-010

http://dx.doi.org/10.1590/1806-9061-2018-0935

Original Article

Productive Performance, Egg Characteristics and Hatching Traits of Three Chicken Genotypes under Free-Range, Semi-Intensive, and Intensive Housing Systems

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■Keywords

Crossbred chickens, egg quality, hatching traits, housing system, live performance.

Submitted: 04/November/2018
Approved: 19/February/2019

ABSTRACT

The present study aimed at evaluating the effect of housing system on the live performance, egg quality, and hatching traits of three dual-purpose chicken genotypes. In total, 180 birds, comprising 48 pullets and 12 cockerels from each of three genotypes, were evaluated during the production phase (27-46 weeks). For this, 144 pullets and 36 cockerels were randomly picked from 18 treatment block groups were shifted to breeding coops, allotting 4 pullets to one cockerel. A completely randomized complete block design (RCBD) was employed. Three genotypes, purebred Naked Neck (NN) and two crosses Rhode Island Red × Naked Neck (RIR × NN = RNN) and Black Australorp × Naked Neck (BAL × NN = BNN), were compared. Intensive system (p<0.0001) and BNN hens (p<0.0001) were heavier on week 26 and 46. Higher egg production (p<0.0001) was obtained in the intensive system and in BNN hens (p<0.0001). Hens maintained in the intensive systems produced heavier eggs and higher egg mass (p<0.0001), and RNN and BNN hens laid heavier eggs (p<0.0001) while higher egg mass (p<0.0001) was found in BNN hens. Higher egg shape index (initial, p=0.0002), egg surface area (initial, p<0.0001; final, p<0.0001), egg volume (initial, p<0.0001; final, p<0.0001) and Haugh unit score (initial, p=0.0002; final, p=<0.0001) were obtained in RNN and BNN hens. At the end of the experiment (46 weeks), higher yolk index (p=0.0004) was found in RNN and BNN eggs, and thicker eggshells (p<0.0001) in RNN eggs. Higher egg hatchability was obtained in the free-range system (p<0.0001) and in the RNN genotype (p<0.0001). The highest fertility rates were detected in the free-range system (p<0.0001), and in the RNN and BNN genotypes (p<0.0001). The lowest infertile egg rates were observed in the free-range system (p<0.0001) and in RNN and BNN genotypes (p<0.0001). The lowest dead-in-shell rate was calculated for the free-range system (p=0.0456). In conclusion, free-range and semi-intensive system largely influence productive performance, egg quality and hatching traits. Regarding genotypes, RNN and BNN crossbred hens perform better than NN purebreds.

INTRODUCTION

In Pakistan, indigenous chickens are reared in rural and peri-urban areas for egg and meat production, which are sources of high-quality protein and also contribute for the nation's GDP (Economic Survey, 2017-18). Indigenous chicken breeds include Aseel, Desi (non-descript) and Naked-Neck; however, some exotic breeds, such as Black Australorp, Fayoumi, Rhode Island Red and their crosses are also reared by the rural farmers (Sadef *et al.,* 2015). Indigenous chicken breeds have become increasingly popular around the globe due to their better adaptability to local environmental conditions and good immune profile (Iqbal *et al.,* 2012).

Egg quality is a major consideration in the egg industry and it is influenced by consumer demands. Furthermore, internal egg content also affects hatching results, particularly chick yield (Rehman *et al.,* 2017). The development of embryonic tissues and efficient hatching require good albumen and yolk quality and are influenced by egg morphometrics. Eggshell thickness is also an important parameter in this regard, as eggshells must be free from any deformities for ideal gas exchange and pipping process, and from hair-like cracks to avoid unnecessary moisture loss. That is the reason why most breeding companies focus on egg-quality traits (Bain, 2005; Sekeroglu & Altuntas, 2009).

Fertility and hatchability are the major constraints that affect the profitability of the hatchery industry and are influenced by genetics, physiology, and extrinsic factors. Peter *et al.* (2008) reported fertility variation among different chicken genotypes and found comparable semen quality and quantity in local Nigerian and exotic chickens. In a study of three exotic and one indigenous chickens of Ethiopia, the highest hatchability (79%) was recorded in indigenous chickens (Lemlem & Tesfay, 2010). Similarly, in dual-purpose chicken genotypes, the highest fertility and hatchability were observed in both pure and crossbred Nigerian chicken genotypes and were attributed to gene segregation (Adeleke *et al.,* 2012).

Housing systems have a substantial effect on live performance and egg quality traits; however, genotypes and feeding regimes are also considered as major factors influencing egg geometry and hatching traits (Chen *et al.,* 2013). Over the last few years, people have become more concerned about the quality and welfare of poultry. In this regard, international regulations have been developed to minimize the use of conventional cage systems and to promote poultry welfare.

Since the ban on conventional cages in 2012 by European Union, producers have been highly motivated to find alternative housing systems, such as enriched cages and free-range and semi-intensive systems (Leinonen *et al.,* 2014). Birds in free-range systems are allowed to graze on seasonal legume and grass pastures, which, in addition, provide earthworms to the birds. Free-range systems not only fulfill the welfare needs of the birds, but the availability of nutritious plants and worms also reduces total production cost (Lay *et al.,* 2011).

Indigenous chickens of Pakistan are generally termed as scavengers; however, their performance in alternative production systems are still unclear. Therefore, present study aimed at evaluating the live performance, egg characteristics and hatching traits of three chicken genotypes (Rhode Island Red × Naked Neck, Black Australorp × Naked Neck, and Naked Neck × Naked Neck) reared under free-range, semi-intensive and intensive housing systems.

MATERIALS AND METHODS

This study was conducted at Department of Poultry Production, UVAS, A-Block, Ravi Campus, Pattoki, Pakistan. Pattoki is located at 31°1′0N and 73°50′60E with an altitude of 186 m (610 ft). This city experiences normally hot and humid tropical climate with maximum temperature ranging from 13ºC in winter and 43ºC in summer.

Ethics

Bird care and use were in accordance with the laws and regulations of Pakistan and was approved by Committee of Ethical Handling of Experimental Birds (No. DR/124), University of Veterinary and Animal Sciences (UVAS), Pakistan.

Experimental birds

One hundred and sixty one-day-old of each genotype: Rhode Island Red × Naked Neck (RNN), Black Australorp × Naked Neck (BNN) and Naked Neck × Naked Neck (NN), totaling 480 chicks, hatched at Avian Research and Training Centre, UVAS, Lahore, Pakistan, were transported to the Indigenous Chicken Genetic Resource Centre (ICGRC), A-Block, UVAS, Ravi Campus, Pattoki.

Chicks were housed in floor pens in a well-ventilated open-sided shed and submitted to standard management conditions until 6 weeks of age. Birds were fed a commercial broiler breeder diet (16% crude protein (CP), 2900 kcal metabolizable energy (ME)/kg). During the brooding period, birds were vaccinated against Newcastle Disease (ND) and Infectious Bronchitis (IB), according to the local schedule.

From 7 to 16 weeks, birds were fed with grower diet (20.02% crude protein and 3020 kcal metabolizable energy (ME)/kg). Morphometric traits were evaluated on weekly basis. At the end of 16 weeks, three birds from each treatment group were randomly collected and slaughtered according to Halal ritual to record carcass traits (Ahmad *et al.,* 2019a).

At 16 weeks of age, out of total of 260 birds (156 pullets and 104 cockerels) remaining from the growing

phase, 156 pullets and 39 cockerels were randomly selected and evaluated during the development phase (16 to 27 weeks of age). Birds were fed with a commercial diet (15% CP, 2750 kcal ME/kg) and their morphometric traits, blood biochemical profile and antibody responses were evaluated (Ahmad *et al*., 2019b).

At 27 weeks of age,180 birds (48 pullets and 12 cockerels of each of the three crosses) were evaluated during the rearing phase. For the egg-production phase, 144 pullets and 36 cockerels were randomly selected from the 18 treatment block groups (3 genotypes × 3 housing systems × 2 sexes) and transferred to laying cages or breeding pens, allotting four pullets per cockerel. Pen-mating system was applied to obtain fertile eggs.

Free-range, Semi-intensive and Intensive Systems

All experimental birds were individually tagged and maintained in an open-sided shed (L × W × H) oriented east to west. A patch of fertile land measuring L × W (stocking density = 0.23/m^2) located in front of the shed was used as range area. The free-range area was enriched with grass and legume species [mung (*Vigna radiata* L.), black-eyed pea *(Vigna unguiculata* L.), French pea (*Phaseolus vulgaris* L.), and alfalfa (*Medicago sativa* L.)]. The range area was divided into two rows using fishing nets (one for free-range and other for semi-intensive). Fresh *ad libitum* water was ensured through manual drinkers. For the protection of the birds, a 2.44m-high wire mesh enclosure was placed surrounding the range area. In the free-range and semi-intensive systems, birds were given access to vegetation and drinking water from 06:00 to 18:00 h, and 06:00 to 12:00 h, respectively (Figure 1).

Figure 1 – Birds in range area

In the intensive system, the laying birds were kept at well-ventilated poultry shed equipped with a three-tier battery cage system with a steep wire floor to facilitate egg collection (FACCO, Poultry Equipment-C3). Under the floor of the cages, dropping belts were placed to collect the fecal material. Floor space of 0.19m^2 per bird was provided.

Experimental diets

The laying hens under the free-range feeding system were offered 100 g of a mixture of seasonal legumes, beans, herbs, and range shrubs twice a day, and were supplemented with a laying breeder feed at 25% of the standard feed allowance (Table 1). Birds in the semi-intensive housing system were also offered the same 100 g of the plant mixture, but once daily and the remaining nutritional requirements were supplied by offering 50% of the standard feed allowance. The birds in the intensive housing system were offered a laying breeder diet as per recommendation of the NRC (1994) and Leeson & Summers (2005) (Table 1).

Table 1 – Ingredient and nutrient composition of experimental ration.

Feed Ingredient (%)	Female formulation (%)	Male formulation (%)
Corn	42.61	39.4
SBM	15.62	10.45
Corn Gluten (60%)	1	--
Rice Tips	19	31
Wheat Bran	13	15.8
DCP	1.2	0.70
$CaCO_3$	7.42	2.65
DL-Methionine	0.15	--
Nutrient		
Crude Protein	15.04	13.13
ME (Kcal/kg)	2682	2848
Calcium	2.81	1.09
Phosphorus	0.34	0.22
Lysine	0.86	0.74
Methionine	0.45	0.39

(Leeson & Summers, 2005).

Parameters evaluated

Eggs were collected daily to calculate hen day production percentage (Shafik *et al.,* 2013), egg weight (g) and egg mass (g). Eggs were stored for 7 days at 13-15°C and 70-80% relative humidity, Eggs were set in the of the Avian Research and Training Centre, UVAS, Lahore, under standard conditions (Victoria Inc.) in order to evaluate hatching results (hatchability, fertility, early embryonic mortality and late embryonic mortality) as adopted by Adeleke *et al.* (2012).

A total of 45 eggs, comprising five eggs per treatment group, were evaluated for morphometry and quality traits at the start and at the end of experiment, according to the methods adopted by Gikunju *et al.* (2018).

Statistical Analysis

The obtained performance, egg characteristics, and hatching trait data were analyzed by two-way analysis of variance, assuming genotypes and housing systems as adjusted effects, applying the General Linear Model procedures of SAS software. Treatment means were separated by Tukey's HSD test (Tukey, 1953) considering significance level of $P \leq 0.05$. The following mathematical model was used:

$$Y_{ijk} = \mu + \beta_i + \tau_j + (\beta \times \tau)_{ij} + \epsilon_{ijk}$$

Where,

Y_{ijk}= Observation of dependent variable recorded on j^{th} housing system in i^{th} block

μ = Population mean

β_i= Effect of i^{th} block (genotype; i = 1, 2, 3)

τ_j = Effect of j^{th} housing system (j = 1, 2, 3)

$(\beta \times \tau)_{ij}$ = Interaction between genotype and housing system

ϵ_{ijk} = Residual error of k^{th} observation on j^{th} treatment in i^{th} block NID ~ 0, σ^2

RESULTS

Productive Performance

Productive performance differed among housing systems, genotypes and their interaction (Tables 2, 3).

Hens maintained in the intensive system were heavier on weeks 26 (p<0.0001) and 46 (p<0.0001) than those in the semi-intensive and free-range systems. Similarly, BNN hens were heavier on week 26 (p<0.0001) and 46 (p=0.0025) compared with RNN and NN hens. In weeks 26 (p<0.0001) and 46 (p<0.0001), BNN hens in the semi-intensive system were heavier than those of the other genotypes.

Hen day production % was higher (p<0.0001) in the intensive system than in the free-range and semi-intensive systems. Relative to genotypes, egg production % was higher (p<0.0001) in BNN hens followed by RNN and NN. The interaction between housing systems and genotype (p<0.0001) showed higher egg production % in RNN and BNN hens kept in the semi-intensive system and BNN chickens with free-range system.

Hens kept in the intensive system produced heavier eggs (p<0.0001) followed by the semi-intensive and free-range systems. Among genotypes, RNN and BNN hens produced heavier eggs (p<0.0001) than NN hens. In the interaction between housing systems and genotypes, higher (p<0.0001) egg weight was found in RNN and BNN hens kept in the intensive and semi-intensive systems.

Higher egg mass (p<0.0001) was obtained in the intensive system, followed by the semi-intensive and

Table 2 – Effect of genotype and housing system on productive performance (26-46 weeks).[1]

Trait	Genotype			P-value	Housing System			*p*-value
	RNN (n = 48)	BNN (n = 48)	NN (n = 48)		FR (n = 48)	SI (n = 48)	I (n = 48)	
BW 26wk	$1228.36^{b} \pm 30.52$	$1366.66^{a} \pm 40.62$	$1064.75^{c} \pm 30.63$	<0.0001	$1082.16^{c} \pm 16.93$	$1215.59^{b} \pm 51.65$	$1362.03^{a} \pm 30.77$	<0.0001
BW 46wk	$1484.45^{b} \pm 100.73$	$1679.74^{a} \pm 99.35$	$1391.25^{b} \pm 72.91$	0.0025	$1171.86^{c} \pm 31.19$	$1467.94^{b} \pm 34.74$	$1915.64^{a} \pm 95.95$	<0.0001
PR	$60.21^{b} \pm 0.14$	$60.71^{a} \pm 0.18$	$54.13^{c} \pm 0.29$	<0.0001	$57.80^{b} \pm 0.59$	$57.56^{b} \pm 0.43$	$59.70^{a} \pm 0.35$	<0.0001
EW	$53.16^{a} \pm 0.15$	$53.13^{a} \pm 0.14$	$46.68^{b} \pm 0.06$	<0.0001	$50.11^{c} \pm 0.36$	$51.31^{b} \pm 0.49$	$51.54^{a} \pm 0.49$	<0.0001
CEM	$4.79^{b} \pm 0.02$	$4.82^{a} \pm 0.02$	$3.80^{c} \pm 0.02$	<0.0001	$4.35^{c} \pm 0.07$	$4.44^{b} \pm 0.07$	$4.62^{a} \pm 0.07$	<0.0001
Liv	99.98 ± 0.01	99.96 ± 0.01	99.97 ± 0.01	0.7898	99.98 ± 0.01	99.95 ± 0.02	99.98 ± 0.01	0.1141

[a-c] Means in a row with no common superscript differ significantly at $p \leq 0.05$.

[1]Values are least square mean ± standard error.

RNN = Rhode Island Red × Naked Neck; BNN = Black Australorp × Naked Neck; NN = Naked Neck; FR = Free Range; SI = Semi Intensive; I = Intensive; BW = Body Weight (g); wk = week; PR = Production %; EW = Egg Weight (g); CEM = Cumulative Egg Mass per bird (Kg); Liv= Livability %.

Table 3 – Interaction effects (genotype × housing system) on productive performance (26-46 weeks)[1].

Trait	RNN			BNN			NN			*p*-value
	FR (n = 16)	SI (n = 16)	I (n = 16)	FR (n = 16)	SI (n = 16)	I (n = 16)	FR (n = 16)	SI (n = 16)	I (n = 16)	
BW 26wk	$1074.54^{e} \pm 15.55$	$1251.15^{c} \pm 23.82$	$1359.40^{b} \pm 20.60$	$1163.73^{d} \pm 14.35$	$1430.93^{ab} \pm 53.39$	$1505.32^{a} \pm 29.37$	$1008.22^{ef} \pm 6.41$	$964.68^{f} \pm 40.90$	$1221.36^{cd} \pm 17.49$	<0.0001
BW 46wk	$1157.92^{ef} \pm 31.66$	$1369.80^{de} \pm 49.82$	$1925.63^{ab} \pm 192.66$	$1318.34^{def} \pm 32.14$	$1606.50^{cd} \pm 36.42$	$2114.37^{a} \pm 182.59$	$1039.31^{f} \pm 6.60$	$1427.51^{cde} \pm 49.07$	$1706.92^{bc} \pm 82.50$	<0.0001
PR	$60.09^{b} \pm 0.15$	$59.43^{c} \pm 0.15$	$61.11^{a} \pm 0.23$	$61.07^{a} \pm 0.20$	$59.67^{bc} \pm 0.29$	$61.40^{a} \pm 0.26$	$52.24^{f} \pm 0.20$	$53.57^{e} \pm 0.14$	$56.60^{d} \pm 0.26$	<0.0001
EW	$51.81^{b} \pm 0.12$	$53.74^{a} \pm 0.08$	$53.92^{a} \pm 0.10$	$51.87^{b} \pm 0.11$	$53.66^{a} \pm 0.06$	$53.85^{a} \pm 0.09$	$46.65^{cd} \pm 0.12$	$46.53^{d} \pm 0.06$	$46.85^{c} \pm 0.10$	<0.0001
CEM	$4.67^{c} \pm 0.02$	$4.77^{b} \pm 0.02$	$4.92^{a} \pm 0.02$	$4.74^{b} \pm 0.02$	$4.78^{b} \pm 0.02$	$4.94^{a} \pm 0.02$	$3.66^{f} \pm 0.02$	$3.76^{e} \pm 0.01$	$3.99^{d} \pm 0.02$	0.0036
Liv	99.98 ± 0.01	99.96 ± 0.03	99.90 ± 0.01	99.97 ± 0.02	99.94 ± 0.04	99.98 ± 0.01	99.99 ± 0.01	99.95 ± 0.02	99.98 ± 0.02	0.7423

a-f Means in a row with no common superscript differ significantly at $p \leq 0.05$.

1Values are least square mean ± standard error.

RNN = Rhode Island Red × Naked Neck; BNN = Black Australorp × Naked Neck; NN = Naked Neck; FR = Free Range; SI = Semi Intensive; I = Intensive; BW = Body Weight (g); wk = week; PR = Production %; EW = Egg Weight (g); CEM = Cumulative Egg Mass per bird (Kg); Liv= Livability %.

free-range systems. As for the effect of genotypes, higher (p<0.0001) egg mass was determined in BNN hens, followed by RNN and NN hens. The interaction between housing system and genotype (p=0.0036) resulted in higher egg mass in RNN and BNN hens reared in the semi-intensive and intensive systems.

Mean livability did not differ among housing systems (p=0.1141) or genotypes (p=0.7898) and no significant interaction (p=0.7423) between factors was detected.

Egg characteristics

Egg morphometry and quality traits of genotypes and their interaction with housing system showed several differences (Table 4, 5, 6, 7).

Initially, egg shape index was higher (p=0.0002) in RNN and BNN hens than in NN hens. The interaction (p=0.0053) between housing systems and genotypes showed that RNN chickens in the semi-intensive system had the highest egg shape index. At the end of the

Table 4 – Effect of genotype and housing system on egg characteristics at 26 weeks.[1]

Trait	Genotype			*p*-value	Housing System			*p*-value
	RNN (n = 15)	BNN (n = 15)	NN (n = 15)		FR (n = 15)	SI (n = 15)	I (n = 15)	
SI	74.24^{a} ± 0.42	73.98^{a} ± 0.38	71.91^{b} ± 0.34	0.0002	73.48 ± 0.39	73.33 ± 0.60	73.32 ± 0.39	0.9503
SA	58.24^{a} ± 0.42	58.13^{a} ± 0.36	55.78^{b} ± 0.35	<0.0001	57.55 ± 0.42	57.31 ± 0.45	57.28 ± 0.57	0.8667
EV	40.92^{a} ± 0.44	40.81^{a} ± 0.38	38.37^{b} ± 0.36	<0.0001	40.21 ± 0.43	39.95 ± 0.46	39.93 ± 0.60	0.8695
EW	44.82^{a} ± 0.48	44.70^{a} ± 0.41	42.02^{b} ± 0.40	<0.0001	44.04 ± 0.47	43.76 ± 0.51	43.74 ± 0.65	0.8702
HU	78.84^{a} ± 0.75	77.23^{a} ± 0.66	74.56^{b} ± 0.39	0.0002	76.53 ± 0.78	76.93 ± 0.82	77.17 ± 0.72	0.7844
YI	49.65 ± 1.14	50.00 ± 0.76	47.94 ± 0.23	0.1883	49.93 ± 0.98	49.42 ± 0.82	48.25 ± 0.59	0.3512
ST	0.33^{ab} ± 0.01	0.32^{b} ± 0.01	0.34^{a} ± 0.01	0.0787	0.34 ± 0.01	0.33 ± 0.01	0.32 ± 0.01	0.0724

$^{a-b}$ Means in a row with no common superscript differ significantly at $p \leq 0.05$.

[1]Values are least square mean ± standard error.

RNN = Rhode Island Red × Naked Neck; BNN = Black Australorp × Naked Neck; NN = Naked Neck; FR = Free Range; SI = Semi Intensive; I = Intensive; SI = Shape Index; SA = Surface Area (cm^2); EV = Egg Volume (cm^3); EW = Egg Weight (g); HU = Haugh Unit Score; YI = Yolk Index; ST = Shell Thickness (mm).

Table 5 – Interaction effects (genotype × housing system) on egg characteristics at 26 weeks[1].

Trait	RNN			BNN			NN			*p*-value
	FR (n = 5)	SI (n = 5)	I (n = 5)	FR (n = 5)	SI (n = 5)	I (n = 5)	FR (n = 5)	SI (n = 5)	I (n = 5)	
SI	73.93^{ab} ± 0.26	75.17^{a} ± 0.76	73.63^{ab} ± 0.93	74.33^{ab} ± 0.69	73.52^{ab} ± 0.86	74.09^{ab} ± 0.44	72.27^{bc} ± 0.64	71.31^{c} ± 0.80	72.24^{bc} ± 0.19	0.0053
SA	58.49^{a} ± 0.52	58.28^{a} ± 0.85	57.94^{ab} ± 0.91	58.10^{ab} ± 0.60	57.65^{ab} ± 0.40	58.64^{a} ± 0.84	56.08^{bc} ± 0.59	55.99^{bc} ± 0.73	55.26^{c} ± 0.58	0.0057
EV	41.18^{a} ± 0.54	40.97^{a} ± 0.89	40.61^{ab} ± 0.94	40.77^{ab} ± 0.62	40.30^{ab} ± 0.42	41.34^{a} ± 0.89	38.67^{bc} ± 0.61	38.59^{bc} ± 0.74	37.84^{c} ± 0.60	0.0060
EW	45.10^{a} ± 0.60	44.87^{a} ± 0.98	44.48^{ab} ± 1.03	44.66^{ab} ± 0.68	44.15^{ab} ± 0.45	45.28^{a} ± 0.97	42.36^{bc} ± 0.67	42.26^{bc} ± 0.81	41.44^{c} ± 0.65	0.0060
HU	78.62^{ab} ± 1.63	79.16^{a} ± 1.16	78.75^{ab} ± 1.34	76.14^{abcd} ± 1.24	77.95^{abc} ± 0.93	77.60^{abc} ± 1.33	74.84^{cd} ± 0.63	73.69^{d} ± 0.85	75.15^{bcd} ± 0.45	0.0088
YI	49.75 ± 2.81	50.20 ± 2.29	49.00 ± 0.53	51.24 ± 1.16	50.40 ± 0.77	48.35 ± 1.73	48.79 ± 0.37	47.65 ± 0.24	47.39 ± 0.33	0.5937
ST	0.34 ± 0.01	0.32 ± 0.00	0.32 ± 0.01	0.34 ± 0.01	0.32 ± 0.01	0.31 ± 0.01	0.35 ± 0.01	0.34 ± 0.01	0.34 ± 0.02	0.1800

$^{a-d}$ Means in a row with no common superscript differ significantly at $p \leq 0.05$.

[1]Values are least square mean ± standard error.

RNN = Rhode Island Red × Naked Neck; BNN = Black Australorp × Naked Neck; NN = Naked Neck; FR = Free Range; SI = Semi Intensive; I = Intensive; SI = Shape Index; SA = Surface Area (cm^2); EV = Egg Volume (cm^3); EW = Egg Weight (g); HU = Haugh Unit Score; YI = Yolk Index; ST = Shell Thickness (mm).

Table 6 – Effect of genotype and housing system on egg characteristics at 46 weeks.[1]

Trait	Genotype			*p*-value	Housing System			*p*-value
	RNN (n = 15)	BNN (n = 15)	NN (n = 15)		FR (n = 15)	SI (n = 15)	I (n = 15)	
SI	77.10 ± 0.82	76.60 ± 1.07	74.21 ± 1.07	0.1067	75.47 ± 1.40	76.47 ± 0.77	75.98 ± 0.84	0.7798
SA	64.75^{a} ± 0.84	65.12^{a} ± 0.71	59.59^{b} ± 0.46	<0.0001	63.01 ± 0.85	63.17 ± 0.97	63.29 ± 1.06	0.9619
EV	47.97^{a} ± 0.93	48.36^{a} ± 0.78	42.35^{b} ± 0.48	<0.0001	46.06 ± 0.92	46.24 ± 1.06	46.38 ± 1.15	0.9566
EW	55.54^{a} + 1.01	52.97^{a} ± 0.85	46.39^{b} ± 0.53	<0.0001	50.45 ± 1.01	50.65 ± 1.16	50.80 ± 1.26	0.9563
HU	82.44^{a} ± 0.77	82.12^{a} ± 0.74	75.38^{b} ± 0.79	<0.0001	80.45 ± 1.22	80.12 ± 0.93	79.37 ± 1.28	0.6153
YI	49.20^{a} ± 2.72	48.00^{a} ± 1.90	37.47^{b} ± 1.51	0.0004	43.00 ± 2.48	43.93 ± 2.15	47.73 ± 2.75	0.2384
ST	0.35^{a} ± 0.01	0.32^{b} ± 0.01	0.28^{c} ± 0.01	<0.0001	0.32 ± 0.01	0.33 ± 0.01	0.31 ± 0.01	0.2441

$^{a-c}$ Means in a row with no common superscript differ significantly at $p \leq 0.05$.

[1]Values are least square mean ± standard error.

RNN = Rhode Island Red × Naked Neck; BNN = Black Australorp × Naked Neck; NN = Naked Neck; FR = Free Range; SI = Semi Intensive; I = Intensive; SI = Shape Index; SA = Surface Area (cm^2); EV = Egg Volume (cm^3); EW = Egg Weight (g); HU = Haugh Unit Score; YI = Yolk Index; ST = Shell Thickness (mm).

Table 7 – Interaction effects (genotype × housing system) on egg characteristics at 46 weeks[1].

Trait	RNN			BNN			NN			*p*-value
	FR (n = 5)	SI (n = 5)	I (n = 5)	FR (n = 5)	SI (n = 5)	I (n = 5)	FR (n = 5)	SI (n = 5)	I (n = 5)	
SI	79.09 ± 1.66	76.17 ± 1.16	76.03 ± 1.19	72.25 ± 2.54	77.36 ± 0.61	77.20 ± 2.14	72.05 ± 2.27	75.87 ± 2.07	74.72 ± 0.76	0.2843
SA	63.79^{a} ± 0.95	65.80^{a} ± 1.33	64.67^{a} ± 2.04	65.91^{a} ± 0.70	63.75^{a} ± 1.89	65.70^{a} ± 0.71	59.32^{b} ± 0.68	59.96^{b} ± 0.27	59.49^{b} ± 1.26	0.0002
EV	46.89^{a} ± 1.04	49.12^{a} ± 1.50	47.90^{a} ± 2.25	49.22^{a} ± 0.78	46.88^{a} ± 2.07	48.99^{a} ± 0.79	42.07^{b} ± 0.73	42.73^{b} ± 0.28	42.26^{b} ± 1.33	0.0003
EW	51.36^{a} ± 1.14	53.80^{a} ± 1.64	52.47^{a} ± 2.47	53.91^{a} ± 0.85	51.35^{a} ± 2.27	53.66^{a} ± 0.86	46.07^{b} ± 0.79	46.81^{b} ± 0.31	46.29^{b} ± 1.46	0.0003
HU	82.49^{a} ± 1.71	81.75^{a} ± 1.54	83.07^{a} ± 0.84	83.49^{a} ± 1.19	81.92^{a} ± 1.41	80.95^{a} ± 1.24	75.36^{b} ± 1.25	76.70^{b} ± 0.54	74.09^{b} ± 1.96	<0.0001
YI	50.40^{a} ± 5.12	44.00^{abc} ± 4.21	53.20^{a} ± 4.76	42.40^{abc} ± 1.75	48.80^{ab} ± 3.77	52.80^{a} ± 2.62	36.20^{c} ± 3.18	39.00^{bc} ± 2.17	37.20^{c} ± 2.85	0.0044
ST	0.36^{a} ± 0.01	0.37^{a} ± 0.02	0.32^{abc} ± 0.02	0.31^{bc} ± 0.02	0.34^{ab} ± 0.02	0.32^{abc} ± 0.01	0.28^{c} ± 0.02	0.29b^{c} ± 0.02	0.28^{c} ± 0.01	0.0012

$^{a-c}$ Means in a row with no common superscript differ significantly at $p \leq 0.05$.

[1]Values are least square mean ± standard error.

RNN = Rhode Island Red × Naked Neck; BNN = Black Australorp × Naked Neck; NN = Naked Neck; FR = Free Range; SI = Semi Intensive; I = Intensive; SI = Shape Index; SA = Surface Area (cm^2); EV = Egg Volume (cm^3); EW = Egg Weight (g); HU = Haugh Unit Score; YI = Yolk Index; ST = Shell Thickness (mm).

experiment (46 weeks), egg shape index did not differ among housing systems (p=0.7798) or genotypes (p=0.1067) and their interaction was not significant (p=0.2843).

The eggs of RNN and BNN hens had larger egg surface area (26 wks, p<0.0001; 46 wks, p<0.0001) than NN hens. The interaction between housing systems and genotypes shows larger egg surface area (26 wks, p=0.0057; 46 wks, p=0.0002) in RNN hens with in all evaluated systems.

Higher egg volume (26 wks, p<0.0001; 46 wks, p<0.0001) was determined in RNN and BNN than in NN genotypes. The interaction between factors showed higher egg volume (26 wks, p=0.0060; 46 wks, p=0.0003) in RNN and BNN hens in all housing systems.

Heavier eggs (26 wks, p<0.0001; 46 wks, p<0.0001) were laid by RNN and BNN hens than NN hens. There was no effect (p>0.05) of housing system on egg weight. However, the interaction between factors showed that the heaviest eggs (26 wks, p=0.0060; 46 wks, p=0.0003) were laid by RNN hens with free-range, semi-intensive and intensive systems and BNN in the intensive system.

RNN and BNN eggs had higher Haugh unit score (26 wks, p=0.0002; 46 wks, p=<0.0001), meaning that their albumen quality was better compared with NN eggs. There was no effect (p>0.05) of housing system on Haugh units. However, the highest Haugh unit scores (26 wks, p=0.0088; 46 wks, p<0.0001) were determined RNN and BNN eggs in all housing systems.

Initially, yolk index did not differ among housing systems (p=0.3512) or genotypes (p=0.1883), and their interaction was not significant (p=0.5937). However, at the end of the experiment (46 weeks), higher (p=0.0004) yolk index was found in RNN and BNN eggs than in NN eggs. The interaction among factors determined the highest egg yolk index (p=0.0044) in the eggs of RNN and BNN hens reared in the free-range and intensive systems.

At the start of the experiment (26 weeks), eggshell thickness was not influenced by housing system (p=0.0724), genotype (p=0.0787) or their interaction (p=0.1800). However, at the end of the experiment (46 weeks), eggs of RNN hens presented thicker eggshells (p<0.0001), followed by those of BNN and RNN hens. The interaction showed that the thickest eggshells (p=0.0012) were produced by RNN and BNN hens reared in the free-range and semi-intensive systems.

Hatching traits

Hatchability, fertility, and infertile egg rates (%) were influenced by housing system, genotype, and their interaction, whereas dead-in-shell rate differed among housing systems, but not among genotypes (Tables 8, 9).

Higher hatchability (p<0.0001) was obtained in the free-range system, followed by the semi-intensive and intensive systems. Regarding genotypes, RNN eggs had the highest (p<0.0001) hatchability, followed by BNN and NN. In the interaction between housing system and genotype, eggs of RNN hens in the free-range system presented the highest hatchability (p<0.0001).

Eggs laid by free-range hens had higher (p<0.0001) fertility compared with the semi-intensive and intensive systems. Among genotypes, RNN and BNN had higher (p<0.0001) egg fertility rate than NN. The interaction among factors showed that free-range RNN hens had the highest (p<0.0001) egg fertility rate.

Egg infertility rate was lowest (p<0.0001) in free-range hens, followed by those kept in the semi-intensive, and intensive systems. Regarding genotypes, RNN and BNN hens had lower (p<0.0001) egg infertility rate than NN hens. The interaction between factors showed that the lowest fertility rate (p<0.0001) was obtained in eggs from free-range RNN hens.

Table 8 – Effect of genotype and housing system on hatching traits.[1]

Trait (%)	Genotype			*p*-value	Housing System			P-value
	RNN (n =15)	BNN (n =15)	NN (n =15)		FR (n =15)	SI (n =15)	I (n =15)	
HP	71.57^{a} ± 1.24	69.24^{b} ±1.37	64.14^{c} ± 1.27	<0.0001	73.61^{a} ± 0.91	67.28^{b} ± 1.39	64.07^{c} ± 0.99	<0.0001
FP	87.43^{a} ± 0.69	86.69^{a} ± 0.90	81.74^{b} ± 1.30	<0.0001	88.42^{a} ± 0.80	84.71^{b} ± 0.83	81.72^{b} ± 1.35	<0.0001
IP	12.57^{b} ± 0.69	13.31^{b} ± 0.90	18.26^{a} ± 1.30	<0.0001	11.58^{b} ± 0.80	15.29^{a} ± 0.83	17.28^{a} ± 1.35	<0.0001
DG	7.91 ± 0.45	8.45 ± 0.76	8.66 ± 0.64	0.6430	7.50 ± 0.50	8.28 ± 0.67	9.24 ± 0.63	0.1168
DIS	7.94 ± 0.49	9.00 ± 0.84	8.94 ± 0.55	0.4154	7.31^{b} ± 0.51	9.16^{a} ± 0.72	9.41^{a} ± 0.57	0.0456

$^{a-c}$ Means in a row with no common superscript differ significantly at $p \leq 0.05$.

[1]Values are least square mean ± standard error.

RNN = Rhode Island Red × Naked Neck; BNN = Black Australorp × Naked Neck; NN = Naked Neck; FR = Free Range; SI = Semi Intensive; I = Intensive; Hp=Hatchability Percent; Fp=Fertility Percent; Ip=Infertile Percent; DG = Dead Germ Percent; DIS = Dead in Shell Percent.

Table 9 – Interaction effects (genotype × housing system) on hatching traits[1].

Trait (%)	RNN			BNN			NN			*p*-value
	FR (n =5)	SI (n =5)	I (n =5)	FR (n =5)	SI (n =5)	I (n =5)	FR (n =5)	SI (n =5)	I (n =5)	
HP	77.29^{a} ± 1.16	69.08^{c} ± 1.22	68.35^{c} ± 1.03	73.43^{b} ± 0.44	70.60^{bc} ± 2.55	63.69^{d} ± 0.75	70.11b^{c} ± 0.85	62.16^{d} ± 1.47	60.16^{d} ± 0.43	<0.0001
FP	90.23^{a} ± 0.84	86.46^{ab} ± 0.79	85.60^{b} ± 0.81	88.35^{ab} ± 1.93	86.37^{ab} ± 0.44	85.34^{b} ± 1.87	86.69^{ab} ± 0.89	81.31^{c} ± 1.47	77.23^{d} ± 1.89	<0.0001
IP	9.77d ± 0.84	13.54^{cd} ± 0.79	14.40^{c} ± 0.81	11.65^{cd} ± 1.93	13.63^{cd} ± 0.44	14.66^{c} ± 1.87	13.31^{cd} ± 0.89	18.69^{b} ± 1.47	22.77^{a} ± 1.89	<0.0001
DG	6.62 ± 0.98	8.71 ± 0.32	8.41 ± 0.63	7.24 ± 0.95	6.98 ± 1.12	11.12 ± 1.09	8.65 ± 0.50	9.14 ± 1.64	8.19 ± 1.11	0.1017
DIS	6.32 ± 0.73	8.67 ± 0.86	8.84 ± 0.46	7.68 ± 1.10	8.78 ± 1.90	10.53 ± 1.28	7.94 ± 0.81	10.01 ± 0.88	8.87 ± 1.08	0.2643

a-d Means in a row with no common superscript differ significantly at $p \leq 0.05$.

[1]Values are least square mean ± standard error.

RNN = Rhode Island Red × Naked Neck; BNN = Black Australorp × Naked Neck; NN = Naked Neck; FR = Free Range; SI = Semi Intensive; I = Intensive; Hp = Hatchability Percent; Fp = Fertility Percent; Ip = Infertile Percent; DG = Dead Germ Percent; DIS = Dead in Shell Percent.

Lower dead-in-shell rate was obtained in free-range hens (p=0.0456) compared with those maintained in the semi-intensive and intensive systems. Dead-in-shell rate was not influenced by genotype (p=0.4154) and its interaction with housing system was not significant (p=0.2643).

No significant differences in embryo mortality were found among housing systems (p=0.1168) or genotypes (p=0.6430) and their interaction was not significant (p=0.1017).

DISCUSSION

The present study evaluated the productive performance, egg characteristics and hatching traits of three chicken genotypes under different housing systems. Hens maintained in the intensive system were heavier in weeks 26 and 46 and showed better productive performance (higher egg weight, egg mass, and egg production, %) than those reared in the semi-intensive and free-range systems. The most likely explanation for the lower body weight of free-range hens is their higher activity and movement in free-range area, which ultimately burns more calories. The observed differences in the productive potential are consistent with the findings of Rehman *et al.* (2016), who found better productive performance of Indigenous Aseel chicken reared under confined and semi-intensive systems. Similarly, Hameed *et al.* (2012) reported better productive performance of different broiler breeder strains maintained under a controlled housing system.

BNN hens were heavier both in weeks 26 and 46 and showed better productive performance compared with RNN and NN chickens. The higher productive potential of BNN hens may be attributed to the combination of Black Australorp and Naked Neck genes, as the Black Australorp is popular for its egg laying potential and Naked Neck for its adaptability to extreme weather conditions, resulting in exceptional egg production and excellent adaptability to local climatic conditions of its cross. These findings arein agreement with the study of Rehman *et al.,* (2016), who found variation in productive performance among different varieties of Aseel chickens (Lakha, Mushki, Peshawari and Sindhi) and reported higher egg production in Peshawari and Sindhi varieties.

Although higher egg shape index was obtained in RNN and BNN hens compared with NN hens at the start of the experiment (26 weeks), no differences among housing systems and genotypes were detected at the end of the experiment (46 weeks). The lack of influence of housing system on egg shape index is in agreement with Rehman *et al.* (2017), who did not find any egg shape index differences among Aseel hens reared in confinement, semi-intensive, or and free-

range production systems. However, variation exists among different varieties of Native Aseel chickens in Pakistan. Literature studies have also reported egg shape index variations among indigenous chickens and laying hens (Van Den Brand *et al.,* 2004; Rayan *et al.,* 2010). In the present study, the eggs of RNN and BNN hens har larger surface area and volume compared with those of NN hens. This difference is consistent with the findings of Rehman *et al.* (2017) and Rayan *et al.* (2010), who found variations in egg surface area and volume among different varieties of Aseel chicken and broiler breeder strains, respectively. It was further noted in that brown broiler breeder eggs had larger egg surface area and volume compared with white egg layers (Rayan *et al.,* 2010). Similar studies reported variation in egg surface area among different strains (Anderson *et al.,* 2004) and breeds (Islam *et al.,* 2010) of chickens.

Higher Haugh unit scores were obtained in eggs of RNN and BNN hens, which indicates that their albumen quality was better compared with eggs of NN hens. This result is in line with the findings of Dunga (2013), who found variation in Haugh unit scores between Naked Neck and Aseel chickens. However, Rajkumar *et al.* (2009) did not report any-significant Haugh unit differences among different chicken genotypes.

Initially, yolk index and eggshell thickness did not differ among housing systems, genotypes, or their interaction. However, at the end of the experiment (46 weeks), higher yolk index and eggshell thickness were determined in the eggs of RNN and BNN hens compared with those of NN hens. Rajkumar *et al.* (2009) also found lower egg yolk index in Naked Neck chickens than normal feathered chickens. Similarly, Dunga (2013) reported variation in yolk index between naked neck and frizzled chickens in India. However, numerous studies did not find any egg shell thickness differences among different chicken genotypes (Hocking *et al.,* 2003; Dukic-Stojcic *et al.,* 2009; Rehman *et al.,* 2017).

Higher fertility and hatchability rates were obtained free-range hens followed by those housed in the semi-intensive and intensive systems. This in agreement with the findings of Oke *et al.* (2015), who reported that rearing guinea fowl on free range improved their reproductive and physiological performance. On the other hand, Mothibedi *et al.* (2016) reported better semen quality traits and ultimately better fertility in Botswana chicken genotypes reared in an intensive housing system.

Regarding genotypes, RNN hens had the highest fertility and hatchability rates. Furthermore, RNN and BNN hens laid less infertile eggs than NN hens. This result agrees with the findings of Adeleke *et al.* (2012), who reported variation in hatching traits between frizzled and normal feathered chickens, where frizzled and normal feather chickens presented 90.5 and 84.8% fertility, respectively, and Anak Titan and Naked Neck showed 80.1 and 76.7% hatchability, respectively. Those authors found that naked-neck chickens had highest dead-in-shells, while Anak Titan had highest embryo mortality.

CONCLUSIONS

Free-range and semi-intensive systems positively influence productive performance, egg quality and hatching traits. Regarding genotypes, RNN and BNN crossbreds perform better than NN purebreds. Hence, RNN and BNN chickens can be useful for rural poultry farmers and can be reared under semi-intensive or free-range housing systems.

ACKNOWLEDGEMENTS

This study was financially supported by Pakistan Agricultural Research Council, ALP fund (Project No. AS-135).

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